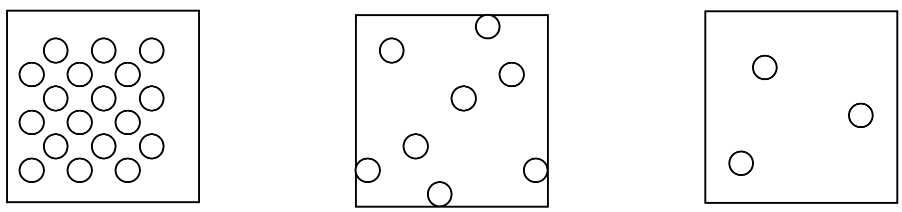
Unit #9
Gases and the Gas Laws
Instructor's notes

Introduction

Remember: Draw three squares with "atoms / molecules" inside each to illustrate the different states of matter.

Identify each as a solid, liquid, or a gas.



Solid *Liquid* *Gas*

1) **Consider the three states of matter pictured above.**
   a) **Which has more entropy ?** *Answer: the gas.*
   b) **Which has more energy ?** *Answer: the gas*

Throughout this unit we will repeatedly return to these diagrams; as we discover how and why the gas laws effect the various properties of a gaseous substance.

Basic Terms

2) Basic Terms (as related to gases)
   a) **<u>Pressure -</u>** The measure of force over a given area. It is caused by the collision of the gas molecules / atoms with the sides of the container.

i) Common units (All of the following are equal to each other):
   (1) 1 atm. = 1 atmosphere
   (2) 760 mm/Hg = the height a column of Mercury is pressed up a glass tube that is sealed at the top, and has its open end in a bowl of Mercury.
   (3) 101.325 KPa = Kilopascals (recall from unit 1, the Pascal was the SI unit for pressure.
   (4) 14.7 psi, or lb/in^2 = Pounds per square inch.

b) **Volume -** The amount of space a gas is filling.

c) **Temperature -** A measure of the average velocity of the gas particles.
   i) Standard temperature = 0^{oC}

d) **Mole -** 1 mole of any gas at "STP" will always equal 22.4 liters.

e) **STP -** Standard Temperature and Pressure.
   i) **Standard Temperature -** 0^{oC} = 273 K
   ii) **Standard Pressure -** 1 atm.

f) **Universal Gas Constant -** An unchanging, numerical value, that "allows" the various units of the gas laws to be combined.

g) **Ideal Gas -** An imaginary gas whose behavior is described by the gas laws.

Observed Properties of Gases

3) **Expansion -** Gases do not have a definite shape or volume. Their shape is determined by the container.

4) **<u>Pressure -</u>** Directly proportional to temperature. As the temp goes up, so does the pressure.

5) **<u>Low Density -</u>** Gases are approximately 1/1000 the density of their solid or liquid phase.
   a) Example: 1.5 grams of "substance A" might have a volume of:
      i) 1.0 mL when a solid
      ii) 1.3 mL when a liquid
      iii) 1050mL when a gas

6) **<u>Diffusion -</u>** The process of spreading out uniformly (without help), to occupy a space uniformly is a characteristic of all gases.

Kinetic Theory of a Gas (Description of a Gas)

7) Defined: A gas consist of very small independent particles (atoms / molecules) that move at random in space; and experience elastic collisions. [This "imaginary gas" is called an Ideal Gas].
   a) **<u>Elastic Collision -</u>** assumes there is no change in Kinetic energy, even after collisions with the inside of the container and each other.

8) **Specific assumptions:**
   a) The molecules are of an ideal mass.
   b) Molecules are in constant, random, straight line motion.
   c) Average Kinetic energy is proportional to the absolute temperature of the molecule.
   d) All collisions are Elastic, (No change in Kinetic energy).
   e) The molecules do not attract or repel each other.

9) **Attractive forces between gas molecules:**

a) **Condensation Temperature -** the lowest temperature a substance can exist as a gas at atmospheric pressure. At this temperature the Kinetic energy of the gas particle is not sufficient to overcome the forces of attraction between the particles. **What are these forces called ?** *Answer: van der Waal forces.*

10) **Boyles Law -** at constant temperature, the volume is inversely proportional to the pressure applied.

a) P↑ V↓ and P↓ V↑

b) $P_1V_1 = P_2V_2$

c) Examples, (assume constant temperature):

i) A 14.5 liter sample of gas is under a pressure of 7.62 KPa. **What will the volume be if the pressure is decreased to 5.54 KPa ?**

Answer:

$$P_1V_1 = P_2V_2$$

$$(7.62\ KPa)\ (14.5\ L) = (5.54\ KPa)\ (V_2)$$

$$19.9\ L = V_2$$

ii) A balloon contains 900 liters of "air" (assumed to be "Ideal") at 1.90 atm. **What is the volume if the pressure is increased to 2.38 atm. ?**

Answer:

$$P_1V_1 = P_2V_2$$

$$(1.90\ atm.)(900\ L) = (2.38\ atm.)(V_2)$$

iii) A piston compresses the contents of a cylinder, which was at a pressure of 620 mm Hg (about 12 psi), from 712.5mL to 64.8mL. **What is the new pressure inside the cylinder ?**

Answer: $P_1V_1 = P_2V_2$

$(620mmHg)(712.5mL) = (X\ mmHg)(64.8mL)$

$6817mmHg = (X\ mmHg)$

iv) A gas at 1 atmosphere of pressure, with a volume of 60 liters is allowed to expand to a volume of 180 liters. **What happens to the pressure ?**

Answer: $P_1V_1 = P_2V_2$

$(1\ atm)(60L) = (X\ atm)(180L)$

$(0.333\ atm) = (X\ atm)$

11) **Charles' Law -** At constant pressure, the volume of a gas is directly proportional to its Kelvin temperature.

a) V↑ T↑ and V↓ T↓

b) $T_1/V_1 = T_2/V_2$ or $T_1V_2 = T_2V_1$

c) Temperature must be in Kelvin.

i) K = C + 273.15

ii) C = K - 273.15

d) Examples, (assume constant pressure):

i) A sample of CO_2 has a volume of 3.50 liters at -10^{oC} .

What will its volume be at 100^{oC} ?

Answer: *First, convert all temps to Kelvin.*

$-10^{oC} + 273.15 = 263.15\ K$

$100^{oC} + 273.15 = 373.15\ K$

Then, solve using Algebra:

$$T_1V_2 = T_2V_1$$
$$(263.15\ K)(X\ L) = (373.15\ K)(3.50\ L)$$
$$(X\ L) = 4.96\ L$$

ii) A 600mL (20 oz.) cylinder is full of CO_2 at 20^{oC}. **What will the temperature be in Celsius, if the volume is dropped to 150mL?**

Answer: *As before convert all temperatures to Kelvin.*

$$20^{oC} + 273.15 = 293.15\ K$$

Then, use Algebra: $T_1V_2 = T_2V_1$

$$(293.15\ K)(150\ mL) = (X\ K)(600\ mL)$$
$$(73.28\ K) = (X\ K)$$

Do we all agree on this answer? *Answer: Should be NO.*

We need to convert our final answer back to Celcius.

$$C = K - 273.15$$
$$C = 73.28 - 273.15$$
$$C = -199.87^{oC}$$

12) **<u>Ideal Gas Law -</u>** the equation: PV = nRT, which relates the: # of moles, volume, temperature, and pressure; of an ideal gas.

a) P = pressure in atmospheres
b) V = volume in Liters
c) n = # of moles of the gas
d) R = the universal gas constant = 0.0821 L * atm / mol * K
   i) Also equal to 8.31451 J / K* mol (often used in Physical Chemistry). We will not be using this value.
      (1) J (Joule) = L * KPa or kg * m^2 / s^2
e) T = temperature in Kelvin

f) **<u>Ideal Gas -</u>** see previous definition as well as the Kinetic Theory defined earlier in this unit.

g) Examples:

i) **What is the pressure of 22.4 liters of a Nitrous oxide that is stored at 32^{oF} ?**

Answer: $PV = nRT$

n = 1 mole (use DIMO to convert liters to moles)

$T = 32^{oF} = 0^{oC} = 0 + 273.15 = 273.15K$

Substituting in the appropriate values we get:

*(X atm.)(22.4 L) = (1 mol)(0.0821 L*atm / mol*K)(273.15 K)*

(X atm) = 1.0011 atm.

ii) **What is the temperature of 1 mole of Oxygen stored at 14.7 psi inside a 22.4 L cylinder?** *Answer ≈ 273.15K (272.838)*

iii) **What is the volume of $6.02*10^{23}$ molecules of H_2S (Hydrogen sulfide) if it is under STP conditions?** *Answer = 22.4 L*

iv) **How many moles of Chlorine would fill a balloon if its internal pressure was 760 mmHg while at a temperature of 32^{oF} and holding 22.4 liters of the gas?**

Answer = 1 mol. (0.998857779 moles)

Practical Applications of the Ideal Gas Law

v) **If an aerosol can with a volume of 750 mL has a pressure of 80 psi is heated from 20^{oC} (68^{oF}) to 60^{oC} (140^{oF}). First, how many moles of the gas are in the can ? Secondly, what is the new pressure in the can ?**

Answer: I suggest making a chart (using the data given in the "problem") like the one that follows for all of these types of problems.

	Initial	**Final**
Pressure	80 psi	y
Volume	750 mL	750 mL
# of Moles	x	x
R	0.0821 L* atm / mol * K	0.0821 L* atm / mol * K
Temperature	20 ^{oC}	60^{oC}

At this point you should be able to see that you first have to solve for "x" in the original problem. You will first have to convert the information into the correct units.

P_i = *5.44 atm*

V_i = *0.75 liters*

n = *x*

R = *0.0821 l * atm / mol * K*

T_i = *293.15 K*

Therefore using $PV = nRT$ $n = 0.1695$ *moles*

P_f = *y*

V_f = *0.75 liters*

n = *0.1695 moles (calculated above)*

R = *0.0821 l * atm / mol * K*

T_f = *333.15 K*

Solving for P_f = *6.18 atm (90.846 psi)*

vi) **p**